DEMONSTRATION: RETORTING OF NEW BRUNSWICK OIL SHALES IN A PILOT SCALE RETORT

Mineral Resources Division
Department of Natural Resources
New Brunswick

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1.0 INTRODUCTION

1.1 Background

The Mineral Development and Processing Department at RPC was requested by Mr. D. Gemmell, Department of Natural Resources, Mineral Development Branch to investigate the feasibility of Co-Utilization of New Brunswick coal and oil shale resources. The general concept being to effect recovery of energy from New Brunswick's appreciable reserve of oil shale whilst the lime content of the shale is utilized to control sulphur effluent problems associated with the province's high sulphur coals.

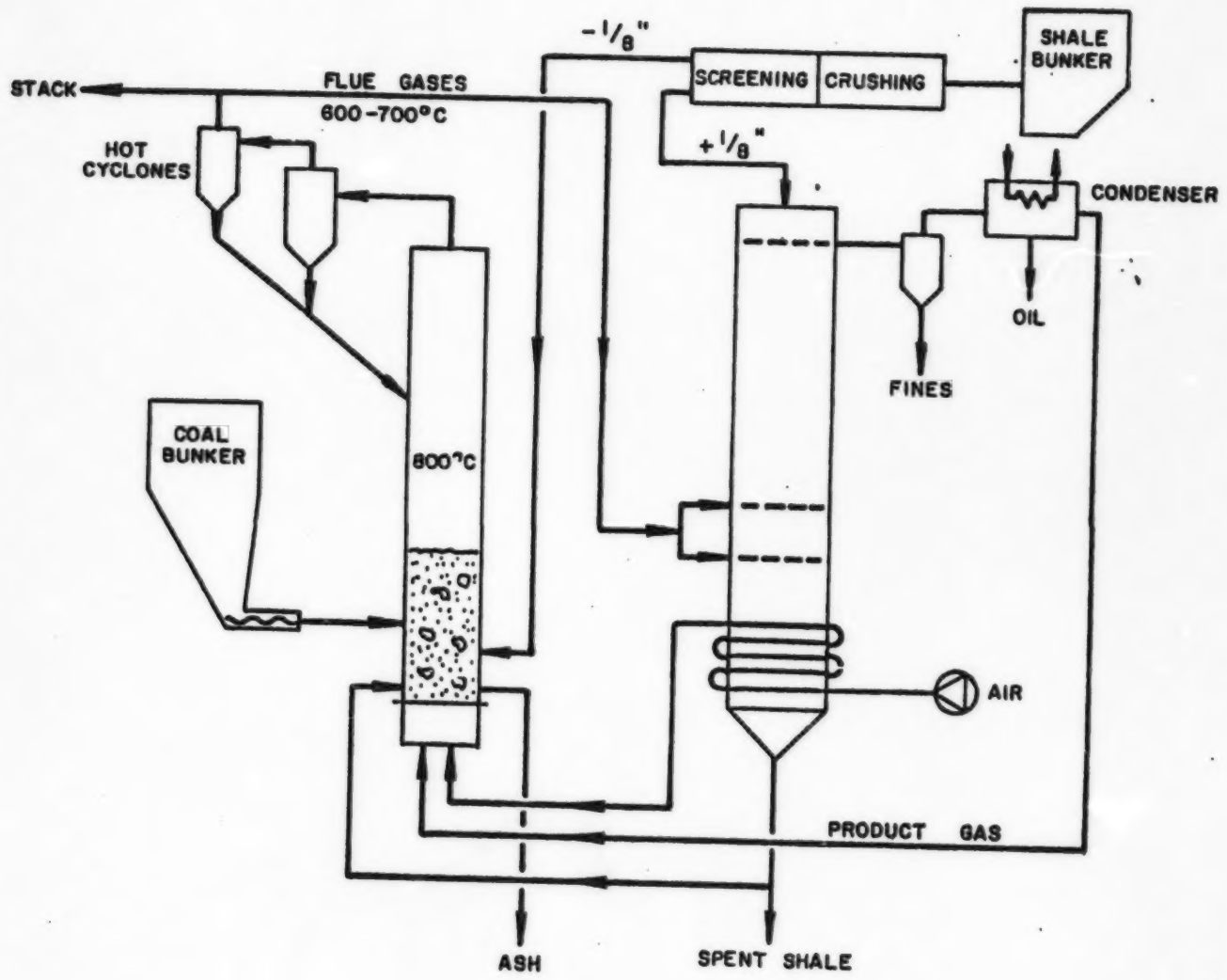
Based on previous preliminary bench scale work, at RPC, several utilization concepts were identified and detailed (1-3). These include: 1) fluid-bed co-combustion of oil shale and coal; 2) fluid bed oil shale combusion scrubbers as an alternative to limestone scrubbers for existing conventional coal fired electrical generating stations, and; 3) oil shale retorting with its process heat requirement supplied from a fluidized combustor operating on high sulphur coal, oil shale fines and spent shale.

1.2 Scope and Objectives: Current Study

This study constitutes the first phase in the development of concept 3 above, namely an integrated fluidized bed coal combustor and oil shale retort system. The concept is outlined elsewhere (4) and also in Figure 1.

The objective of this phase of the work was to "Design, Construct and Test a Pilot Scale Retort System", and to provide preliminary test data to be used in future optimization trials with an interlock coal combustor.

FIG 1: AN INTEGRATED FLUIDIZED BED COMBUSTOR AND INDIRECT OIL SHALE RETORT SYSTEM



2.0 CONCLUSIONS

A pilot scale oil shale retort was designed, constructed and successfully operated on New Brunswick, Albert Mines oil shale. The main conclusions of the work are as follows:

1. The retort temperature profile is critically important to achieving high oil yields.

2. Oil yields are sensitive to variations in shale and gas feed rates.

3. A reduction in shale residence time (less than 3.8 hour) is possible without loss in product yields.

4. Improvements in oil yields will be possible through improvement in the efficiency of the oil mist collection system.

5. The oil shale used in this study was of a relatively low grade with a Fischer assay of 9.3 gal/ton. This may have contributed toward lowering the oil recovery. However, despite this and difficulties with the oil recovery system, up to 77% of the oil content of the shale, based on its Fischer assay, was recovered.

6. The product oil is lighter than those from Green River oil shales, its' characteristics being more similar to Arabian light crude.

3.0 RECOMMENDATIONS

With the pilot scale oil shale retort operating successfully, work can now proceed with the integrated coal combustion/oil shale retort trials.

Prior to the assembly of the integrated system, the following optimization work is recommended:

1. improving the existing oil recovery system.

2. more trials; using a higher grade shale are recommended, in order to optimize the retorting process and to generate complete mass and energy balances.

3. investigating the effect and the significance of shale particle size distribution on the retorting process.

4. investigate the indirect retorting process as a preliminary step toward implementing the integrated oil shale retort and a fluidized bed coal combustion system.

4.0 EXPERIMENTAL WORK

4.1 Process Description

In this study the retort was operated in the gas combustion retorting mode, which is widely applied in large scale continuous operations. In this type of operation, (see Figure 2) oil shale flows by gravity downward through a vertical retort as a moving bed. The shale flow rate being controlled by a discharge mechanism located in the lower part of the retort.

It is convenient to imagine the retort as being divided into four functional zones, although there are no physical separations installed in the retort. The four zones are the preheat zone, the retorting zone, the combustion zone, and the spent shale cooling zone.

Combustion air plus some recycle gas are injected into the bed of shale in the combustion zone. Fuel in the recycle gas burns in air to generate heat. Some residual carbon which is present on shale particles in this hot zone also is burned, liberating heat and gaseous products of combustion.

Some cool recycle gas is introduced into the bottom of the retort to cool hot spent shale flowing downward from the combustion zone. The flow of gases in the retort is upward, counter to the downward flowing of solids, providing direct gas to solids heat exchange.

4.2 Experimental Set-up

The major effort in this study was the design and construction of the pilot scale retort system, shown schematically in Figure 3. The system consists of three main subsystems, these are as follows:

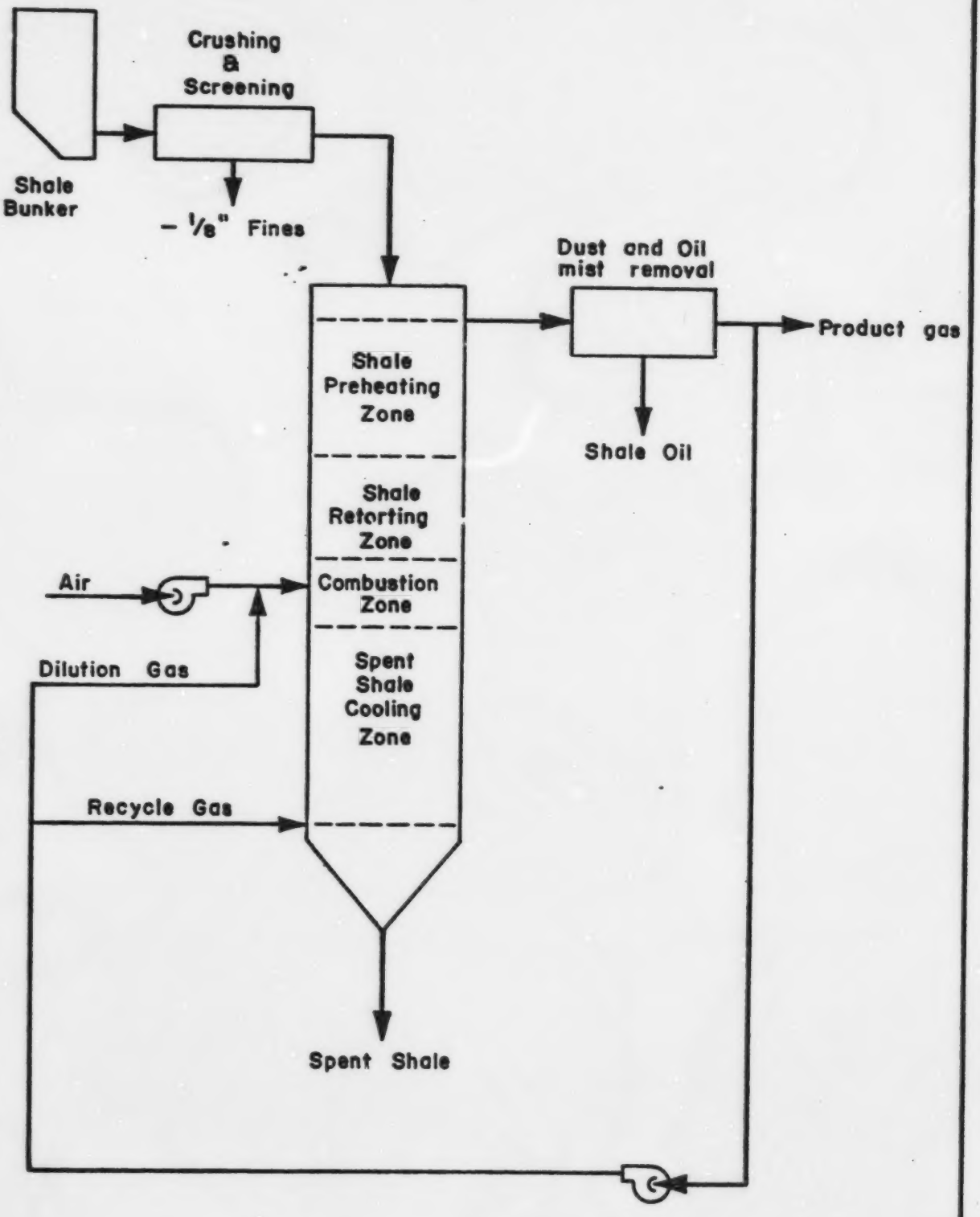


FIG 2: DIRECT RETORTING PROCESS

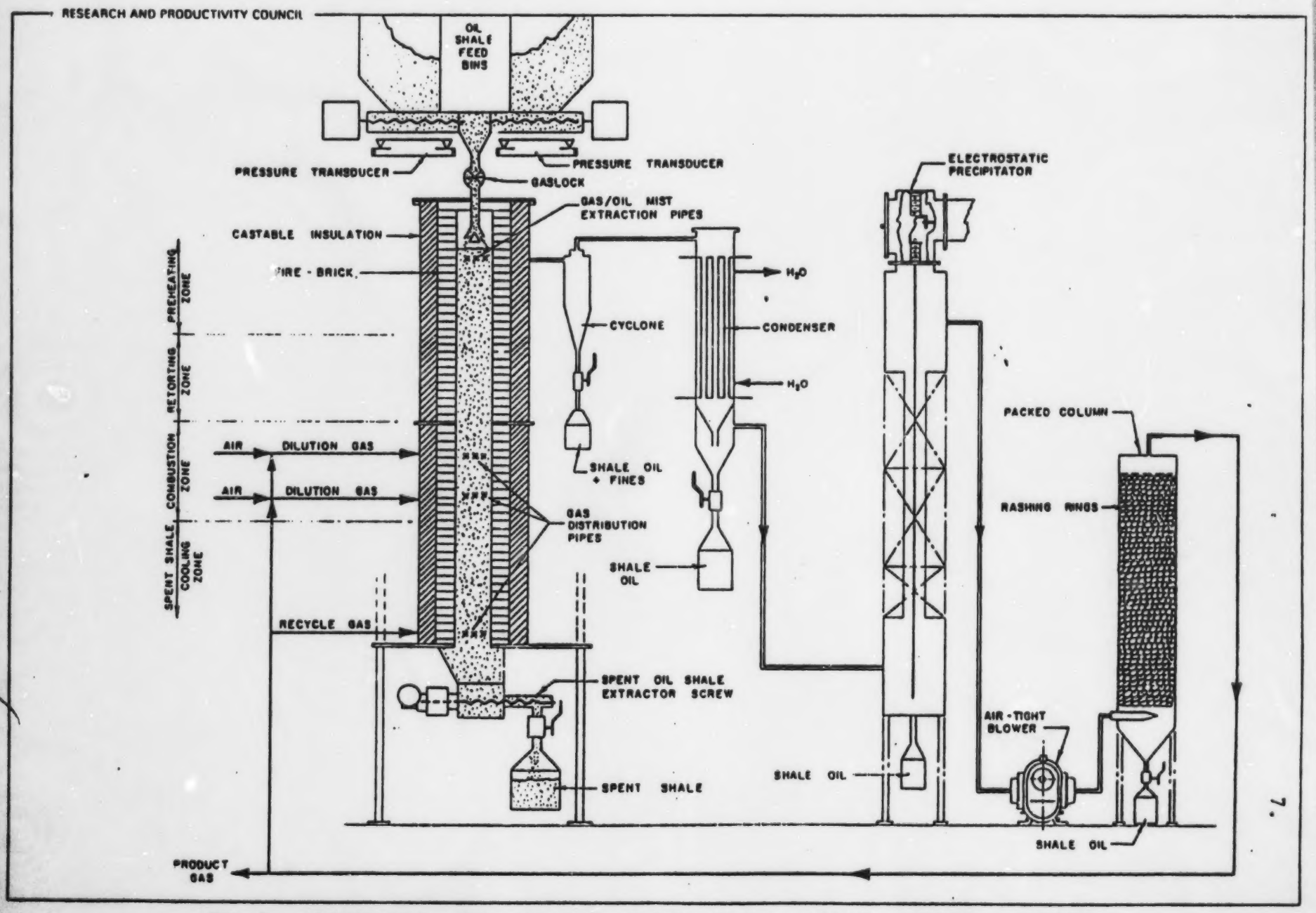


FIG 3: SCHEMATIC VIEW OF THE R.P.C. PILOT SCALE RETORT SYSTEM

a) the retort itself;
b) solid feeding and withdrawal systems;
c) product oil recovery system.

4.2.1 The Retort

The retort was constructed from high alumina brick with an internal square cross-sectional area of 0.052 m^2 (0.23 x 0.23 m) and a total height of 2.4 m. The high alumina brick was selected because of its good chemical, abrasion and thermal shock resistance.

The brick layer was followed (inside to outside) by a castable insulating refractory and an external carbon steel shell. The outside dimensions of the retort were 0.6 x 0.6 m.

The retort was fitted with a number of side doors constructed from high temperature castable refractory to facilitate the insertion of air and gas distribution tubes as well as thermocouples.

4.2.2 Solid Feeding and Withdrawal System

Oil shale feeding bins were located above the retort so that gravitational feeding would be possible. Two bins were installed each of which was mounted on four pressure transducers (weight cells) for feed rate measurements. Each bin was also fitted with a conventional screw feeder fitted with a variable speed motor for controlling the feed rate. Both bins supplied a common hopper which was followed by a star valve (gas lock). The latter then discharged into the retort.

Solid withdrawal was by means of a screw feeder, again fitted with a variable speed motor for controlling the discharge rate.

4.2.3 Product Oil Recovery System

This system consisted of a cyclone, a condenser, an electrostatic precipitator and a packed column, in this order. The cyclone was used for shale fines and heavy oils collection. This was followed by a shell and tube heat exchanger with a heat transfer area of 0.5 m^2.

The electrostatic precipitator (ESP) which has an effective height (distance between input and exit parts) of 3 m and a pipe diameter of 0.25 m, was supplied by Joy Manufacturing. The total height of the unit was 6 m.

Due to difficulties with the ESP (continuous arcing and poor collection efficiency) a packed tower was added at a later date. The diameter of the column was 0.37 m, with an effective height of 1.68 m.

4.3 Start-up Procedure

The retort was started-up on propane, with the upper gas distributer pipes used as a burner. Before firing the burner the retort was first filled with shale to 0.1 to 0.15 m below the burner. The burner was then ignited and the brick work was heated for 2-3 hours until a temperature of 800-900°C was reached. The burner was then shut off and shale and air were introduced into the retort.

To avoid shale fusion the bed must be kept in motion. This was achieved by adjusting the shale discharge rate to about one-third of the feed rate.

From a cold start to steady state operation took an average 7-9 hours.

4.4 Experimental Measurements

Experimental measurements consisted of shale feed and discharge rate, air and gas stream flow rates and bed temperature profile. The latter was measured using 17 thermocouples the location of each is shown in Figure 4.

The rate of accumulation of product oil and water were measured at half-hour intervals. The spent shale was weighed at one hour intervals as a check on the calibration of the bottom screw feeder. All products from each individual run were kept separately for subsequent analysis.

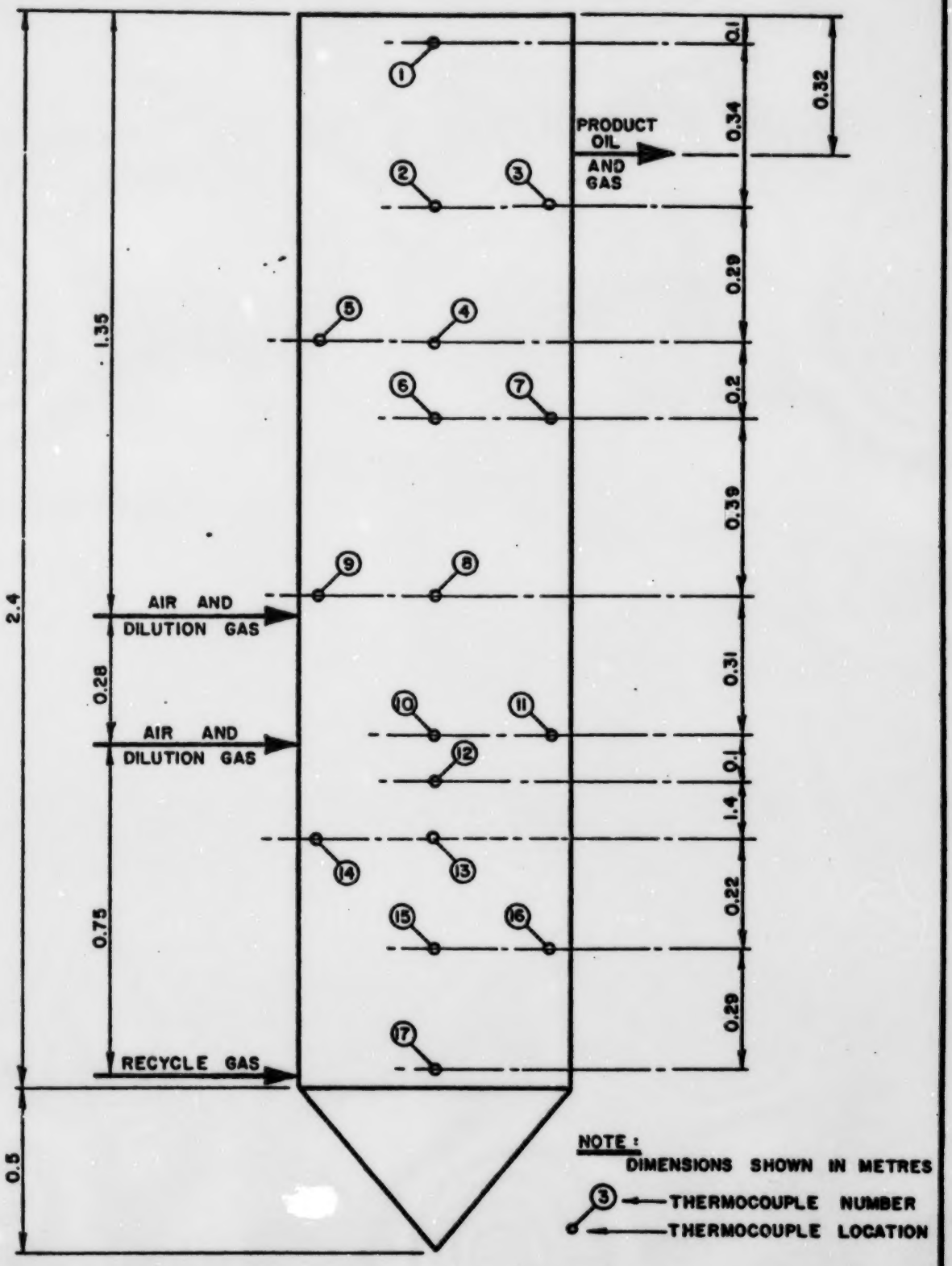


FIG 4: SCHEMATIC OF THE RETORT SHOWING POSITIONS OF THERMOCOUPLES AND GAS DISTRIBUTION AND WITHDRAWAL PIPES

5.0 RESULTS AND DISCUSSION

5.1 Experimental Results

5.1.1 Feed Stock Characterization

The oil shale supplied by the Department of Natural Resources consisted of four lithotypes. In stratigraphic sequence these are the Upper Shale, Albert Mines Zone, Clay Marlstone Zone and the Dolomite Marlstone Zone. For a detailed geological report, see reference (5). The Fischer Assay of the four lithotypes are given in Table 1 while their Ultimate and Ash Analyses are given in Table 2.

The quantities of separate lithotypes were not sufficient for individual characterization, therefore, all but the Upper Shale were blended. The Fisher Assay of the blend is shown in Table 1.

The raw shale as supplied, contained in excess of 60% fines which had to be removed. The particle size distribution of the shale used in this study is given in Table 3.

5.1.2 Operating Conditions and Products Yields

Several experimental runs have been carried out, however, only the results from the last four tests are included in this report. The early trials were designed to debug the system and to gain operating experience. As a result of these tests the start-up procedures described above were established and modifications for the solid feeding and withdrawal system were determined, also the need for additional insulation and an electrostatic precipitator for oil mist collection were identified and implemented.

TABLE 1: FISCHER ASSAY

Quantity	Upper Shale	Albert Mines Zone	Clay Marlstone Zone	Dolomite Marlstone Zone	Blend**
Total Loss %	4.0	7.5	6.0	7.5	7.5
Oil Wt. %	1.4	4.9	3.3	4.8	4.1
Volume Oil * (ml @ 15.5 °C)	1.6	5.6	3.7	5.4	4.7
% H_2O Yield	2.2	1.5	1.5	1.1	1.6
% Gas Lost	0.4	1.1	1.2	1.6	1.9
Oil Yield * (Imp. gal/ton)	3.1	11.2	7.4	10.8	9.3

* An assumed density of 0.8768 gm/cc @ 15.5 °C was used in calculating these values.

** All lithotypes but the Upper Shale.

TABLE 2: ULTIMATE AND ASH ANALYSIS OF LITHOTYPES

	Upper Shale	Albert Mines Zone	Clay Marlstone Zone	Dolomite Marlstone Zone
Utimate Analysis: wt%				
Organic Carbon	2.75	7.40	6.18	7.25
Inorganic Carbon	3.07	3.45	2.97	1.70
Hydrogen	0.83	1.26	1.07	1.05
Nitrogen	0.21	0.15	0.07	0.24
Sulphur	0.77	0.82	0.73	0.67
Oxygen	10.67	10.48	9.98	9.25
Ash	81.70	76.44	79.00	79.84
Ash Analysis: wt%				
Na_2O	3.60	1.72	2.40	2.65
K_2O	3.43	2.26	2.32	2.43
CaO	10.22	11.84	9.26	8.10
MgO	5.62	5.77	6.60	5.82
Fe_2O_3	7.79	7.91	8.01	8.08
Al_2O_3	24.48	19.64	20.39	21.58
SiO_2	44.86	50.86	51.02	51.34

TABLE 3: SHALE PARTICLE SIZE DISTRIBUTION

Screen Size	Weight %
-5/8" + 3/8"	10.9
-3/8" + 1/4"	22.7
-1/4" + 5 mesh	30.3
- 5 mesh + 8 mesh	36.1

The operating conditions for tests 1 to 4 are summarized in Figures 5 to 8, respectively, see also Table 4. The ten data points which constitute the retort temperature profile are averages of readings from thermocouples 1 to 17 shown in Figure 4.

Due to difficulties with the electrostatic precipitator (arcing), it was decided to include the packed column shown in Figure 3. However, this modification only took place after the second test, therefore, it is only applicable to the last two tests.

5.1.3 Products Yields and Properties

Oil, gas and spent shale yields are summarized in Table 4. Shale oil was collected at four different locations, these in sequence were the cyclone, the condenser, the electrostatic precipitator (ESP), and the packed column.

The total yield of oil for each run and its distribution among the different collection locations is shown in Table 5. The properties of the oil derived from each run are shown in Table 6. Also, chromotograms of all oil products are given in Appendix A.

Spent shale analysis were limited to the determination of organic and inorganic carbon content shown in Table 7. Product gas yields are given in Table 4 and gas chromatograms are given in Appendix A.

5.2 Discussion

The main operating parameters in this study were shale feed rate (shale residence time), and gas feed rates. Varying these parameters led to wide variations in oil yields and properties.

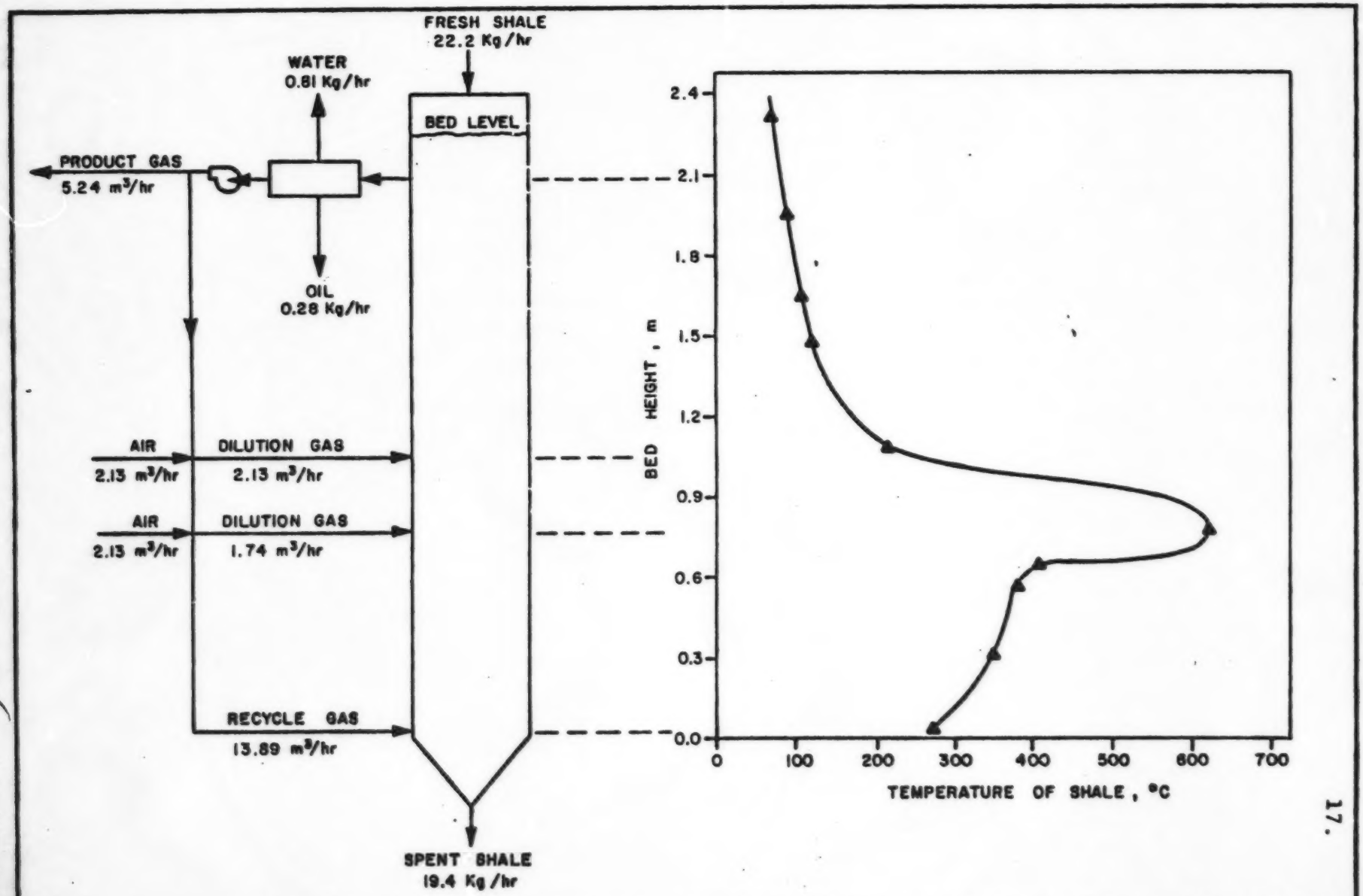


FIG 5: OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR TEST NO:1

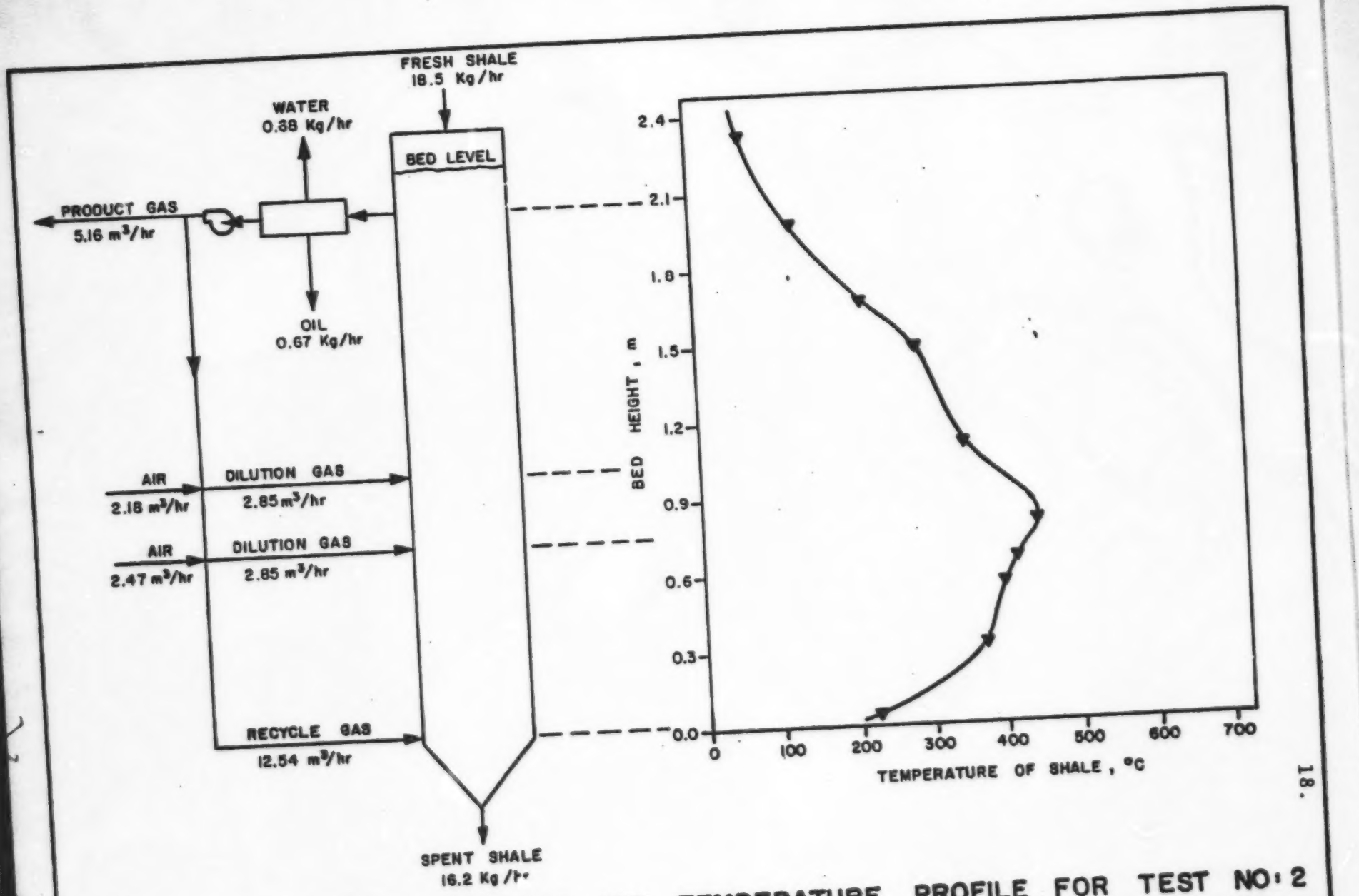


FIG 6: OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR TEST NO: 2

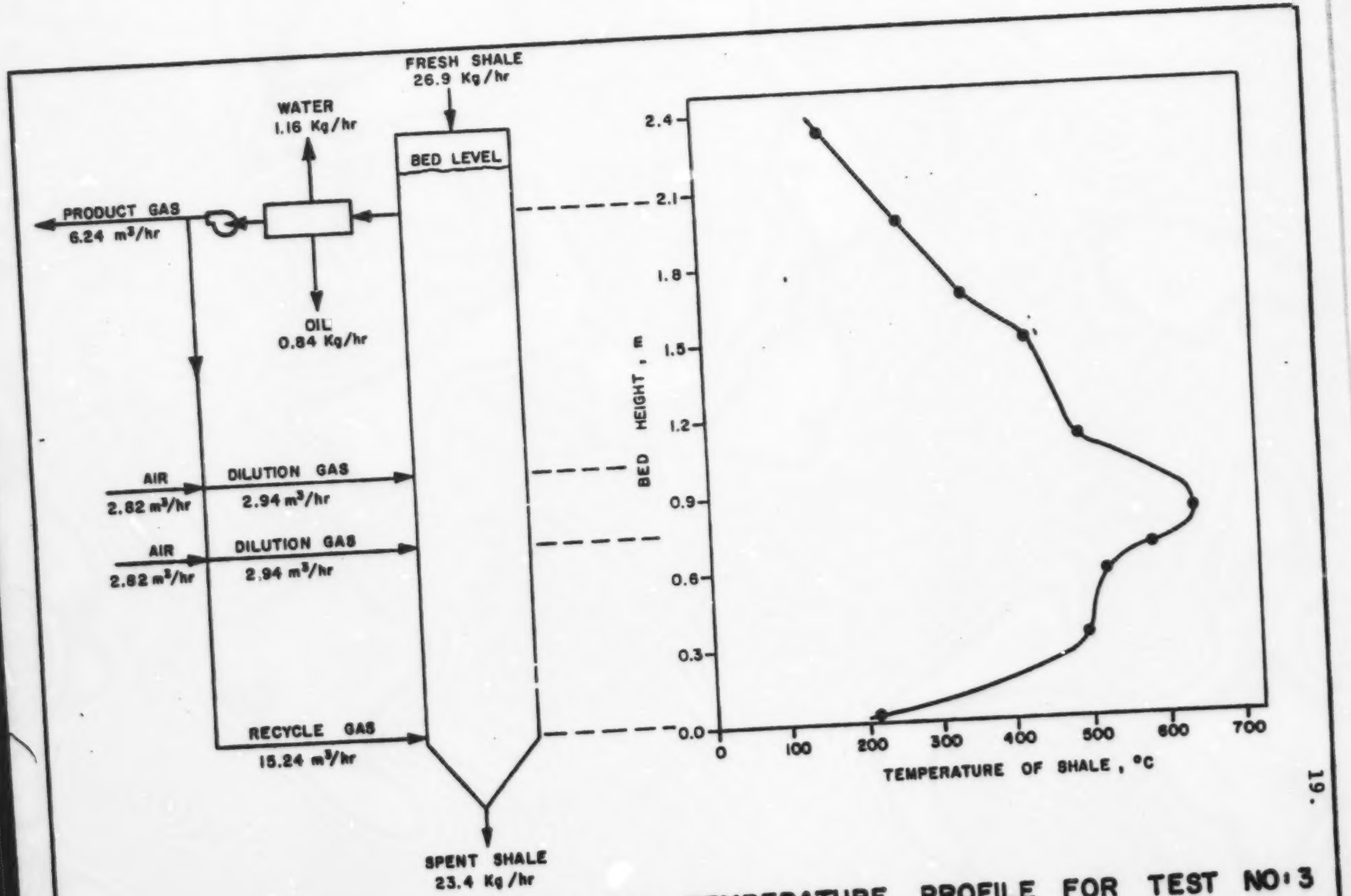


FIG 7: OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR TEST NO: 3

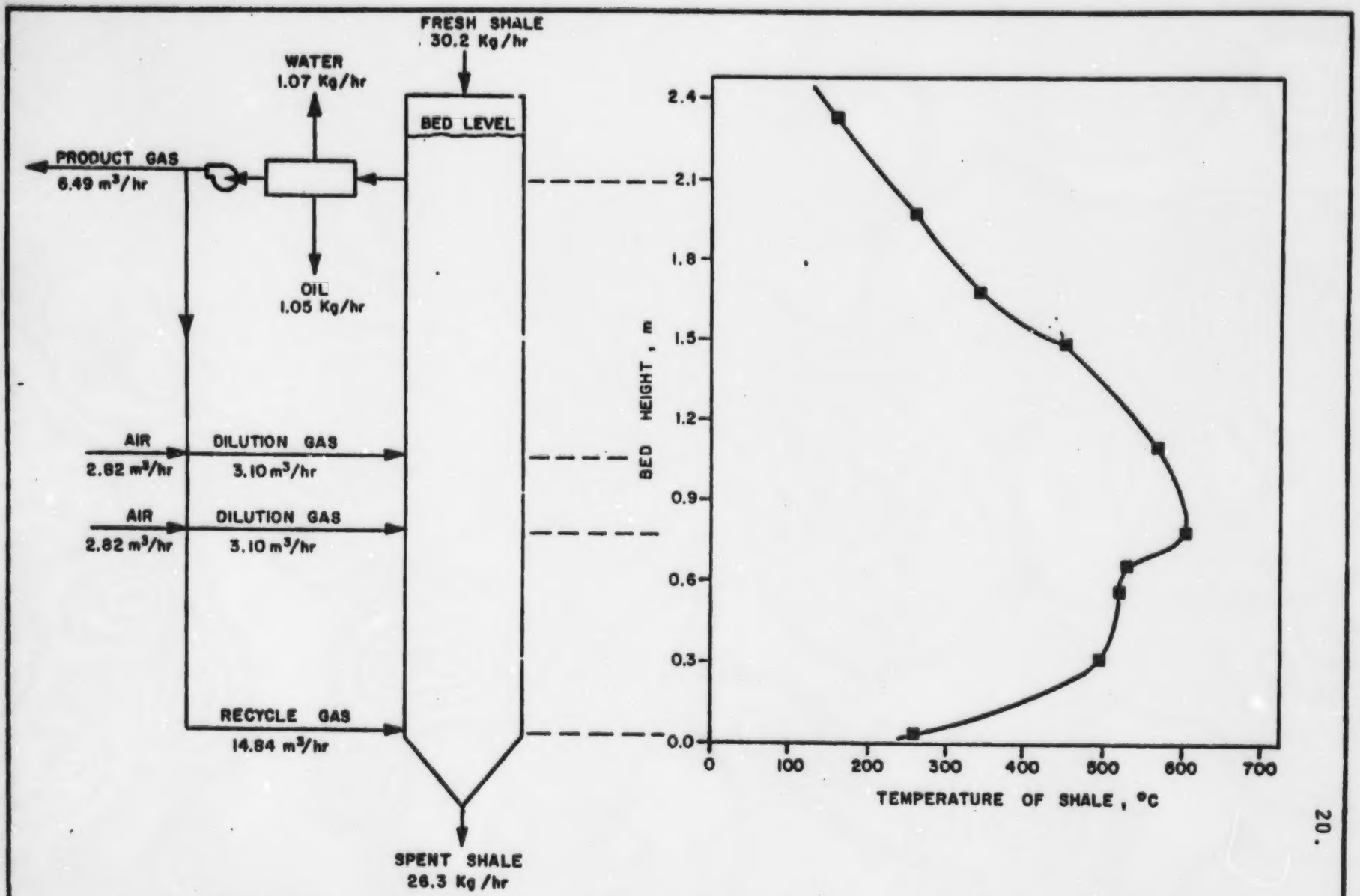


FIG 8: OPERATING CONDITIONS AND TEMPERATURE PROFILE FOR TEST NO: 4

TABLE 4: OPERATING CONDITIONS AND PRODUCT YIELDS

		Test Number			
		1	2	3	4
Length of test at steady state	hours	6	8	6	7.5
Rates and Quantities:					
Bed height	m	2.3	2.3	2.3	2.3
Raw shale feed rate	kg/hr	22.2	18.5	26.9	30.2
Air feed rate	m^3/hr	4.26	4.65	5.64	5.64
	m^3/ton	191.9	251.4	209.7	186.8
Dilution gas rate	m^3/hr	3.9	5.7	5.9	6.2
	m^3/ton	174.3	308.1	218.6	205.3
Recycle gas rate	m^3/hr	13.89	12.54	15.24	14.84
	m^3/ton	625.7	677.8	566.5	491.4
Shale residence time	hours	5.2	6.2	4.3	3.8
Yields:					
Oil	vol %/Fisher assay	30.5	77.3	67.1	74.3
Product gas	m^3/hr	5.24	5.16	6.24	6.99
	m^3/ton	236.0	278.9	232.0	214.9
Spent shale	kg/hr	19.4	16.2	23.4	26.3
Liquid water	kg/hr	0.8	0.7	1.2	1.1

TABLE 5: SHALE OIL YIELD AND DISTRIBUTION

Test No.	Total Yield (liters)	Cyclone %	Condenser %	ESP %	Column %
1	1.897	54	27	19	0
2	5.338	29	44	27	0
3	5.063	19	48	28	5
4	7.875	6	58	18	18

TABLE 6: SHALE OIL PROPERTIES

Test No.	Sample Location	Gravity Specific	Gravity API	Viscosity CPS	Pour Point °C	Calorific Value BTU/lb	Sulphur wt%	Nitrogen wt%	Carbon wt%	Hydrogen wt%	C/H Ratio
1	Cyclone	0.8922	27.1	8.18	- 2	19,188	0.41	0.11	86.39	12.55	6.88
	Condenser	0.8254	39.9	2.30	-44	19,369	0.67	0.19	86.81	12.89	6.73
	ESP	0.8266	39.7	2.75	-41	19,210	0.56	0.12	85.36	12.12	7.09
2	Cyclone	0.9136	23.4	14.30	+ 7	18,830	0.61	0.33	86.80	12.83	6.77
	Condenser	0.8632	32.4	7.92	0	18,947	0.60	0.21	86.62	12.05	7.19
	ESP	0.8852	28.4	4.94	- 8	18,793	0.68	0.11	86.07	12.31	6.99
3	Cyclone	0.9716	14.1	150.00	+15	18,913	0.41	0.13	87.15	12.26	7.10
	Condenser	0.8806	29.2	9.30	+ 2	19,205	0.51	0.15	86.67	12.44	6.97
	ESP	0.8594	33.3	5.70	- 3	18,847	0.44	0.27	85.85	11.98	7.17
	Column	0.8624	32.6	9.15	+ 3	18,977	0.53	0.27	87.03	12.33	7.06
4	Cyclone	0.9170	22.8	124.00	+ 6	18,982	0.49	0.31	87.04	12.61	6.90
	Condenser	0.8672	31.7	10.00	+ 3	19,027	0.42	0.34	87.29	12.30	7.10
	ESP	0.8792	29.4	7.20	0	18,667	0.35	0.30	86.24	12.21	7.06
	Column	0.8780	29.7	7.20	+ 1	19,248	0.52	0.15	86.80	12.84	6.76

TABLE 7: CARBON ANALYSIS OF FRESH AND SPENT SHALE SAMPLES

Carbon wt%	Fresh Shale Blend	Spent Shale from Tests 1	2	3	4
Total Carbon	9.34	2.20	4.06	3.42	2.41
Organic Carbon	6.72	0.91	1.91	1.71	0.93
Inorganic Carbon	2.62	1.29	2.15	1.71	1.48

5.2.1 Effect of Operating Parameters on Retort Temperature Profile and Product Yields

The importance of the retort temperature profile cannot be over-emphasized, as it represents the time-temperature history of shale particles. As a result of varying shale, gas and air feed rates, markedly different temperature profiles and consequently a wide variation in oil yields were obtained. For ease of comparison the four temperature profiles given in Figures 5 to 8 are superimposed and shown in Figure 9.

The retort temperature profile is a complex function of a number of physical and chemical processes. Therefore in order to offer an explanation for the effect of the various operating parameters on the retort temperature profile, and product yields, it is necessary to make the following simplifying assumptions:

a) The retort will be considered to consist of a heat source which includes the combustion and shale cooling zone and a heat sink consisting of the retorting and shale preheating zones.

b) There is no heat generation in the retorting zone.

c) Heat is transferred between source and sink predominantly by upward moving gases.

As mentioned earlier, see Section 4.1, the shale particles move downward by gravity into four functional temperature zones. However, in terms of oil recovery only the preheating and retorting zones are of significance. This is because once the particle reaches the combustion zone, which starts at approximately 450°C, most of the Kerogen will be consumed by combustion. For this reason, it is important

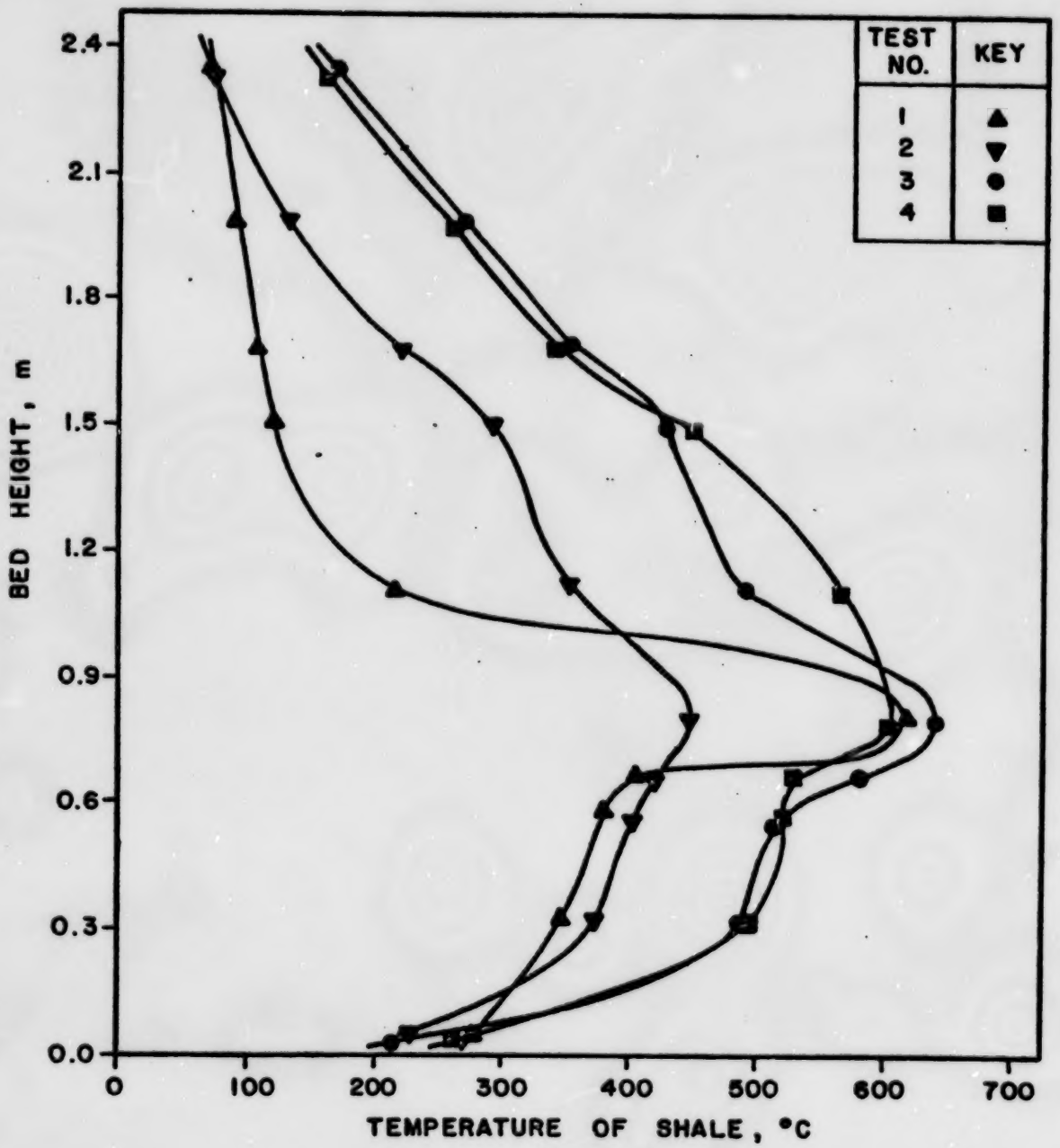


FIG 9: TEMPERATURE PROFILES FOR TESTS "1" TO "4"

to maintain a sufficient residence time in the retorting zone. In the discussion below, emphasis will be on reactions in the retorting and preheating zones, and in the combustion zone.

Reactions in the combustion zone are fairly rapid because of rapid kinetics and good mixing (high temperature, therefore high gas velocities). Therefore, the maximum temperature in the combustion zone is simply a function of air/fuel ratio, calorific value and reactivity of the fuel and the rate of heat losses.

In test 2, the maximum temperature was approximately 450°C. This was a result (see Table 4) of a combination of high air feed rate and a low shale feed rate (air/feed rate of 251.4 m^3/ton of shale). In the remaining tests, the ratios of air to shale feed rates were considerably lower. The maximum temperatures for these tests were in the range 600-650°C.

Based on previously mentioned assumptions the shale particles in the retorting zone derive energy mainly through heat transfer from hot combustion gases leaving the combustion zone. Factors which affect the rate of heat transfer are, gas temperature and velocity, shale particle size distribution, the degree of solid mixing and solids residence time.

Gas velocity is a function of both gas mass feed rate (or volumetric feed rate at normal temperature and pressure as given in Figures 5 to 8 and Table 4) and gas temperature. Solid mixing, on the other hand, is a complex function of particle shape, size distribution, bulk density, state of agglomeration, temperature, etc. In general, increased mobility of individual particles will promote mixing, i.e., increasing the shale feed (and discharge) rate will result in

better mixing.

A comparison between test 1 and tests 3 and 4 shows that air/shale ratios are similar. However, in test 1, the feed rates of air, gases and shale are approximately 20% lower than tests 3 and 4. Therefore for test 1, heat losses and poor solid mixing could account for the very low retorting zone temperature. Consequently the descending shale entered the combustion zone (starts at approximately 450°C) where most of the heavy oil fraction was consumed via combustion. This resulted in poor oil yield. Tables 6 and A-1 confirm that only the very light oil fraction was retorted (product oil has low specific gravity, viscosity, pour point, boiling, point, etc.).

In test 2, as mentioned above, the high air/shale ratio, led to a low combustion zone temperature and a very wide retorting zone. This test gave the highest oil yield, approximately 2.5 times the yield for test 1. It is also significant to notice that the spent shale from this test has the highest residual carbon content, as a result of low carbon consumption in the combustion zone, see Table 7.

The temperature profiles for tests 3 and 4, are quite similar. A comparison of the oil recovery for tests 3 and 4 shows, that the recovery for test 3 is 10% lower than that for test 4. The shale feed rate for test 4 is approximately 12% higher than that for test 3. Also, in test 3 there could be losses in oil recovery due to oil being trapped on the intersticies of the newly installed packed column. Table 5 shows the oil recovery in the column is only 5% as compared to 18% for test 4.

Oil recovery for tests 4 and 2 are very similar and both are fairly high. This is despite the fact that their operating conditions are different. For example, the shale

feed rate for test 4 is approximately 60% higher than that for test 2. This suggests that the high oil recovery in test 2 was achieved through an extended retorting zone which resulted from a very high air/shale ratio, while in test 4, this is probably due to a high degree of solid mixing and high gas velocity.

It is important to note that increasing the retort throughput (without sacrificing oil recovery) is an important optimization parameter, as it will impact directly on the capital cost the retort. Therefore the operating conditions for test 4 should be considered as nearer to the optimum as compared to test 2.

5.2.2 Comparison with Other Work

The temperature profiles for tests 3 and 4 resembles that achieved in the USBM 150-ton retort (7). The exception being that the combustion zone temperature of the USBM retort is approximately 100°C higher than was achieved in tests 3 and 4. There are several reasons which might account for this difference. First, it is possible that optimization of the operating conditions might lead to a temperature profile similar to USBM retort. It is also possible because of the difference in scale, that the higher heat losses for this small retort will always limit the temperature in the combustion zone. Also, it has been shown that operable gas and shale feed rates and consequently the retort temperature profile are functions of retort hardware (7). The Paraho retort which has a similar design to the USBM retort, but operates on slightly different mode (steam is injected into the retorting zone) has a combustion zone temperature, which is almost equal to those achieved in test 3 and 4.

As shown in Table 6, the oil product from test 1 is considerably lighter than is the oil from the other three

tests, also within the same test there is considerable variation in the physical properties depending on where the oil has been collected in the recovery train. For comparison purposes with data for Green river oil shale, oils from test 1 will be excluded because it is exceptionally light due to the reasons given earlier (heavy oil fraction was not recovered, low oil yield, etc.). Also, the properties of the remaining oils will be indicated as a range showing maximum and minimum values as shown in Table 8.

The quality of New Brunswick shale oil produced with the RPC retort is compared in Table 8 with Arabian light crude and shale oil produced from colorado shales via six different retort set-ups. New Brunswick shale oil has a lower sulphur and much lower nitrogen content, and a lower C/H ratio, as compared to oils produced from colorado oil shale.

The physical properties of New Brunswick shale oil, particularly the pour point, also suggest that this may be a lighter crude than is that produced from colorado shales. As such, New Brunswick shale oil with its higher yield of light fraction should be a superior crude for refining. As a fuel New Brunswick shale oil would also yield considerably lower NO_x and SO_x emissions than would the colorado shale oil.

Typical oil yields from direct retorting processes are 80-85% based on the Fischer Assay. In this study an oil recovery of 77% was achieved. Several factors contributed to the lower oil yield, these are as follows:

a) operating conditions are not fully optimized.

b) difficulties in collecting oil mist due to the poor efficiency of the electrostatic precipitator.

c) oil losses during separation from product water and

TABLE 8: COMPARISON OF SHALE OIL PROPERTIES WITH PRODUCTS FROM OTHER RETORTING PROCESSES*

Parameter	RPC	Arabian Light Crude	Dravo	Pharoho	Tosco II	Union B	Oxy-MIS	USBM**
Retort Method	Direct	-	Direct	Direct	Indirect	Indirect	Direct	Direct
API Gravity	33.3-14.1	34.7	20.8	19.3	21.2	22.7	24-25	21.2
Pour Point, °C	-8-+15	-26	29.4	29.4	26.7	15.6	10-18.3	29.4
Viscosity @100°F; CPS	5.70-150.00	5.5	75.0	78.5	27.1	98.0	15.8	18.1
Sulphur, wt%	0.35-0.61	1.71	0.98	0.71	0.67	0.9	0.64	2.12
Nitrogen, wt%	0.11-0.34	0.08	1.82	2.00	1.85	2.00	1.50	2.10
C/H Ratio	6.76-7.17	6.2	7.41	7.40	7.30	7.30	7.20	7.42

* source - reference 6
** source - reference 7

elutriated fines.

d) the reccveries quoted from the work of others are from high grade Green River oil shale with an oil content of 28-30 gal/ton, while the shale used in this study contained only 9.3 gal/ton. Also, these recoveries quoted for the Green River oil shale were derived from larger scale retorts. These two factors are probably the principle reasons for the lower recoveries indicated in this study.

e) the shale used in this study had a very wide particle size distribution with an appreciable amount of fines (36% less than 5 mesh) this large variation in particle size could cause poor heat and mass transfer and consequently loss in oil yield.

Despite the above difficulties the retort was operated successfully and there is scope for improving the oil yield in future research programs.

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7.0 ACKNOWLEDGEMENTS

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RESEARCH AND PRODUCTIVITY COUNCIL
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8.0 APPENDICES

APPENDIX A
ANALYSIS OF PRODUCT OIL AND GAS

Oil Analysis

One of the methods commonly used for characterization of petroleum products is the American Society for Testing Materials (A.S.T.M.) distillation, which is simple batch distillation carried out according to the rigorously specified procedure given in the A.S.T.M. Book of Standards.

The results are usually reported in terms of the temperatures at which 10, 20, 30, etc., percent of the original charge has been distilled. Therefore, if a high percent was distilled at a low temperature, this indicates a light oil and the reverse is true.

In this study, however, chromotography has been used for the same purpose. Chromotograms of all product oils are shown in Figure A-1 to A-14. The area under each peak represents a hydrocarbon with a given boiling point. Also the chromotograph was calibrated so that the position of the peaks corresponding to straight chain saturated hydrocarbons were identified. These were the peaks marked on the chromotograms, the number given corresponds to the number of carbon atoms. Knowing the boiling points of these hydrocarbons, we were able to calculate the percentage of oil which boils within these temperature ranges, see Table A-1.

The table shows the weight percent of oil boiling below the indicated temperatures. The results are consistent with those given in Table 6. For example, oils from Test 1 are much lighter than the remaining tests. Also, within the same test the general trend, with few exceptions, is that the oil gets lighter as it progresses through the oil recovery train,i.e., cyclone, condenser, electro-static precipitation

TABLE A-1: BOILING POINTS OF OIL PRODUCTS

Oil Weight % Cumulative

	Test 1			Test 2			Test 3				Test 4			
Temp. (°C)	Cyclone	Condenser	ESP	Cyclone	Condenser	ESP	Cyclone	Condenser	ESP	Column	Cyclone	Condenser	ESP	Column
126	3.4	2.1	0.9	3.8	6.1	6.0	4.2	0.9	8.0	0.5	6.7	0.7	1.4	2.0
174	3.4	10.6	8.2	3.8	12.5	11.4	4.4	6.5	12.6	4.4	6.7	10.4	6.7	4.6
216	5.6	46.3	44.0	5.9	29.8	35.2	5.3	26.4	30.0	16.5	7.3	23.3	26.0	14.2
254	17.5	80.5	77.7	13.7	48.3	59.8	8.3	45.3	53.1	32.7	12.3	40.8	50.3	34.7
287	44.4	93.9	91.6	31.9	60.7	76.1	17.3	58.8	69.1	51.8	24.0	55.3	64.7	62.0
316	68.8	97.6	95.9	55.0	72.9	86.1	34.9	70.6	81.7	71.1	43.5	68.0	76.0	80.4
343	84.0	99.1	98.2	73.2	83.0	92.3	56.2	81.3	89.4	84.5	63.0	79.7	84.8	89.4
413	98.5	100.0	100.0	96.8	98.7	99.3	94.3	97.5	99.4	98.6	95.6	97.7	98.5	98.9

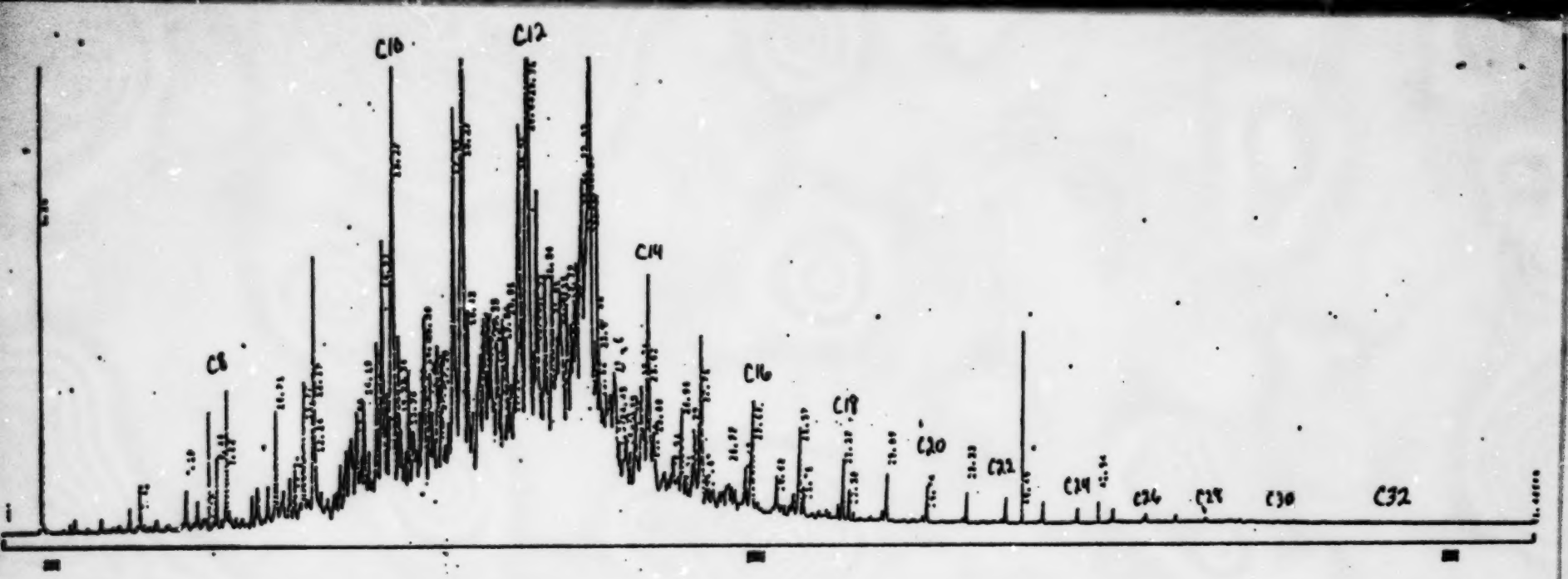

Figure A-1: Chromotogram for Test 1 (Cyclone)

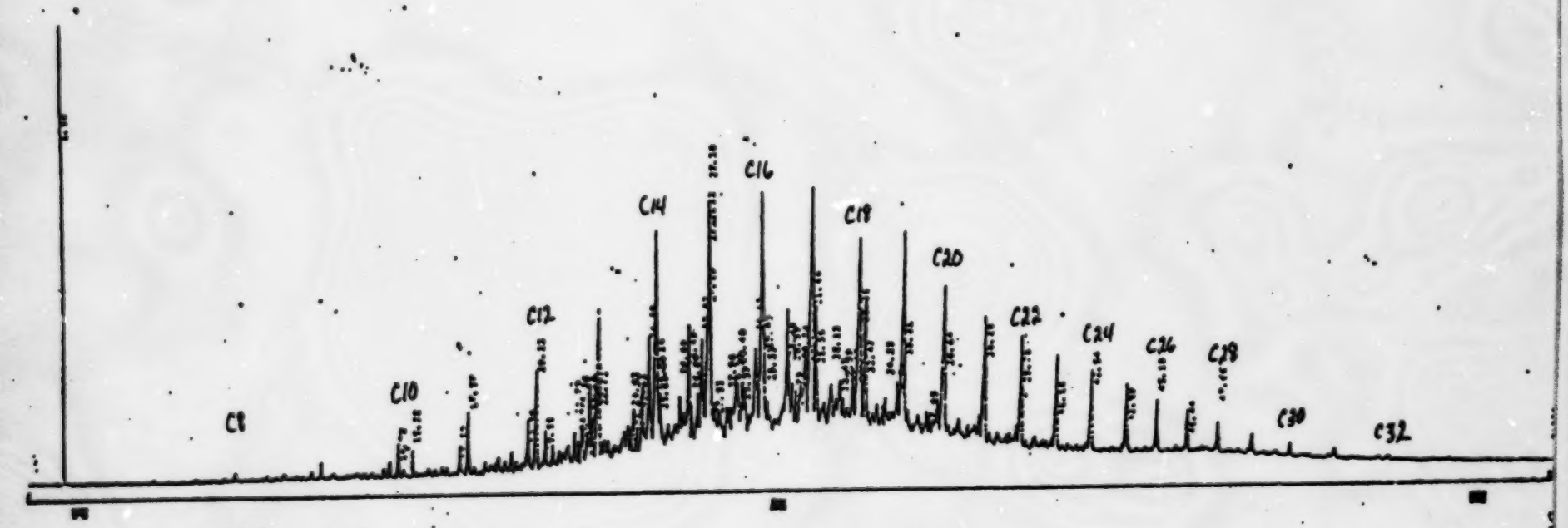

Figure A-2: Chromotogram for Test 1 (Condenser)

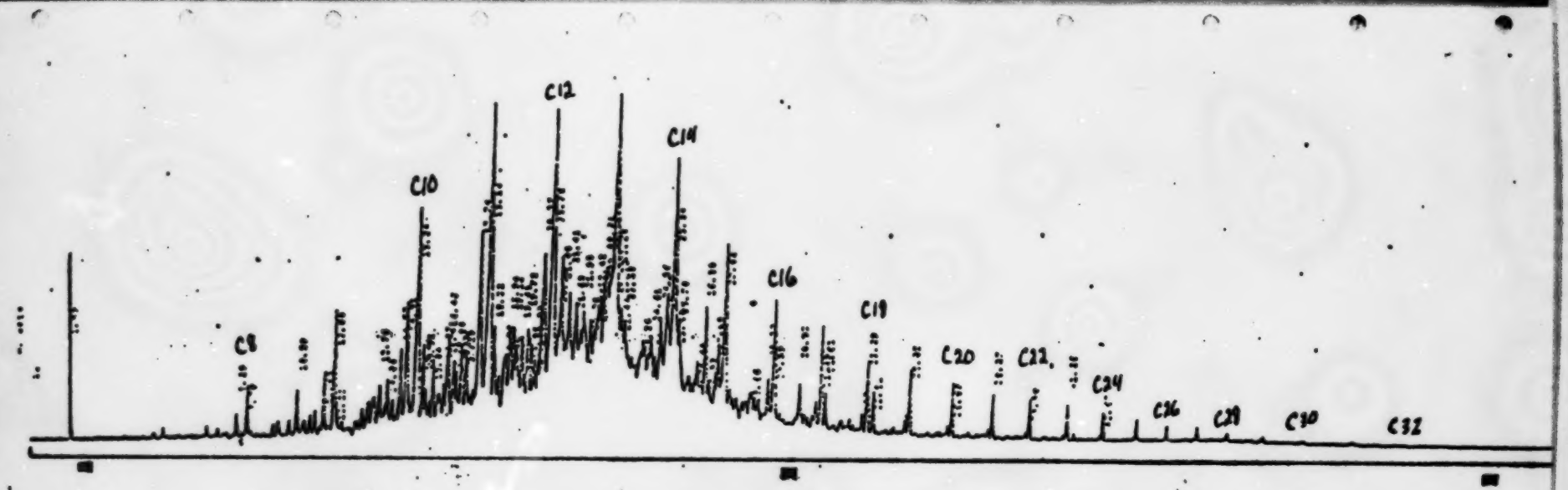

Figure A-3: Chromotogram for Test 1 (ESP)

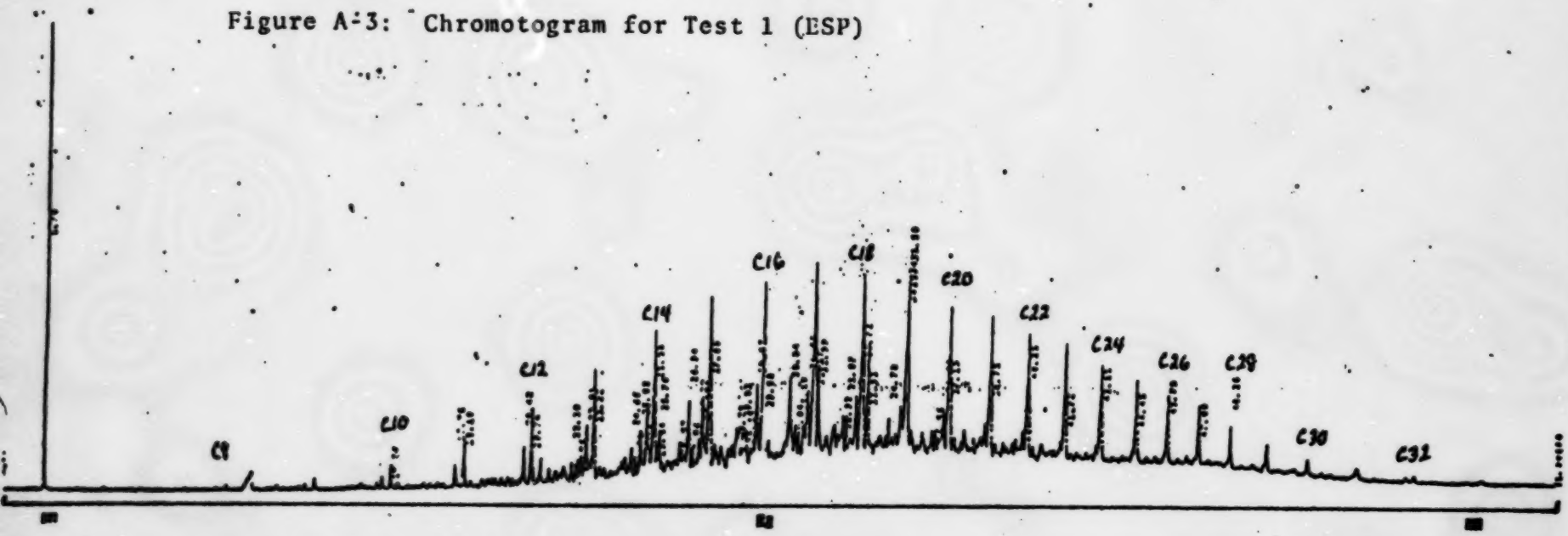

Figure A-4: Chromotogram for Test 2 (Cyclone)

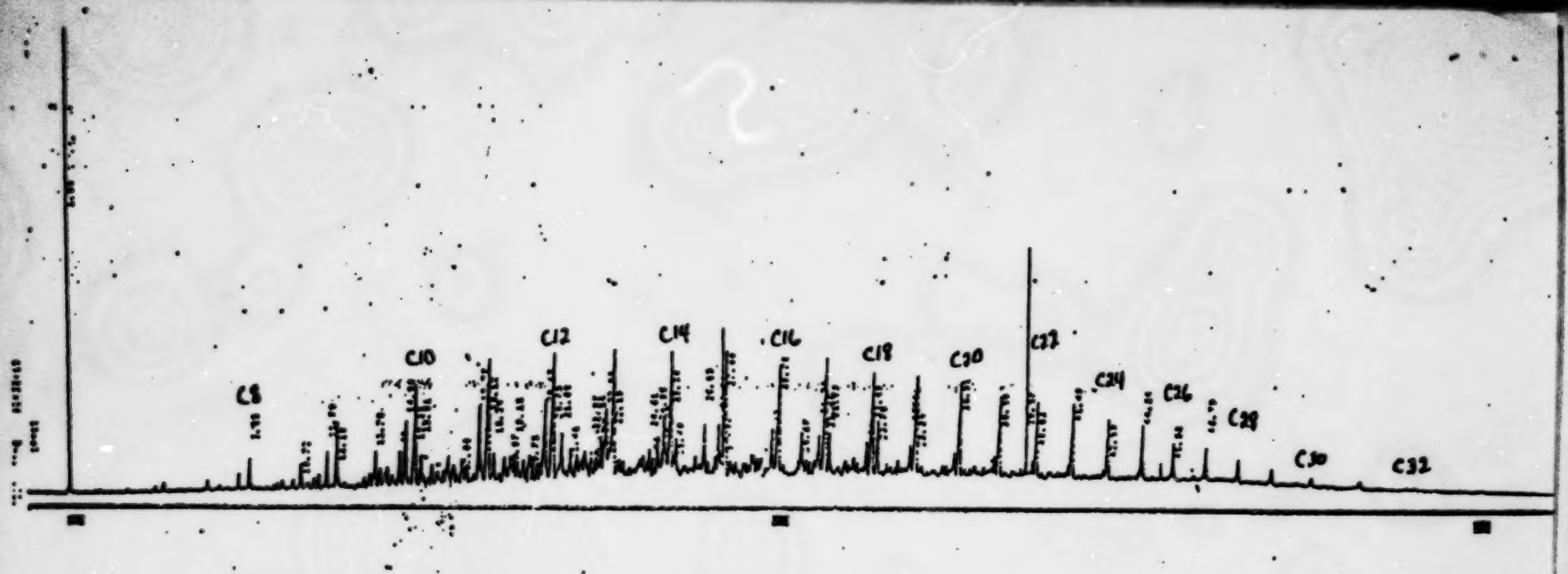

Figure A-5: Chromotogram for Test 2 (Condenser)

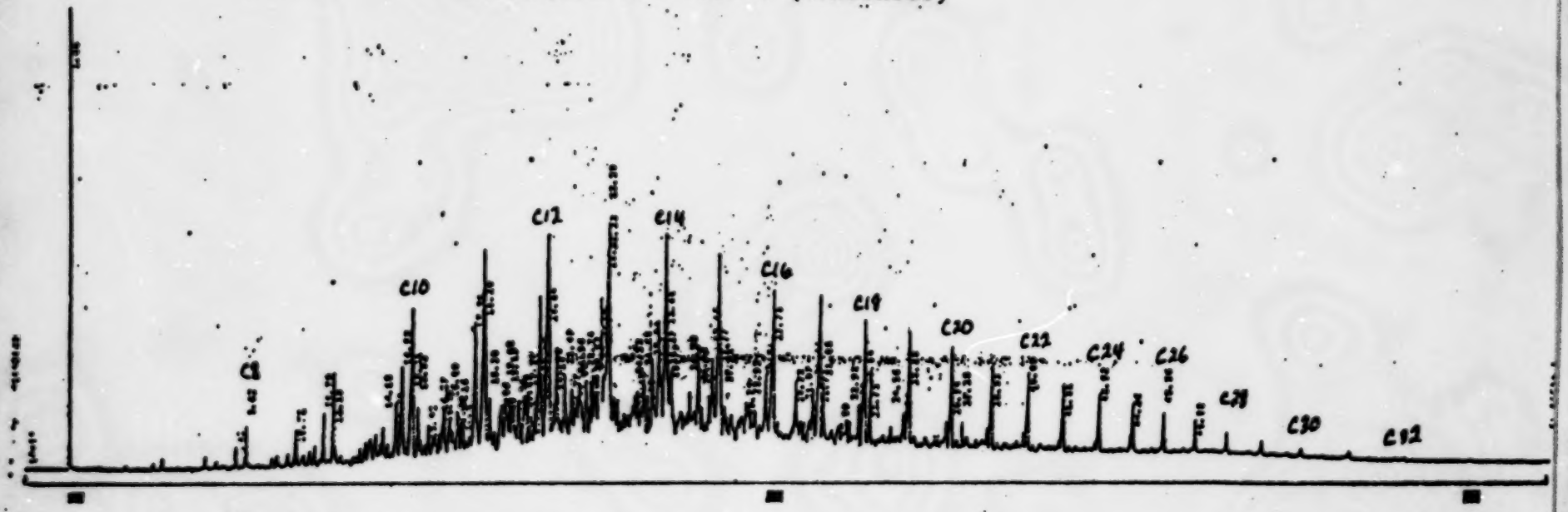

Figure A-6: Chromotogram for Test 2 (ESP)

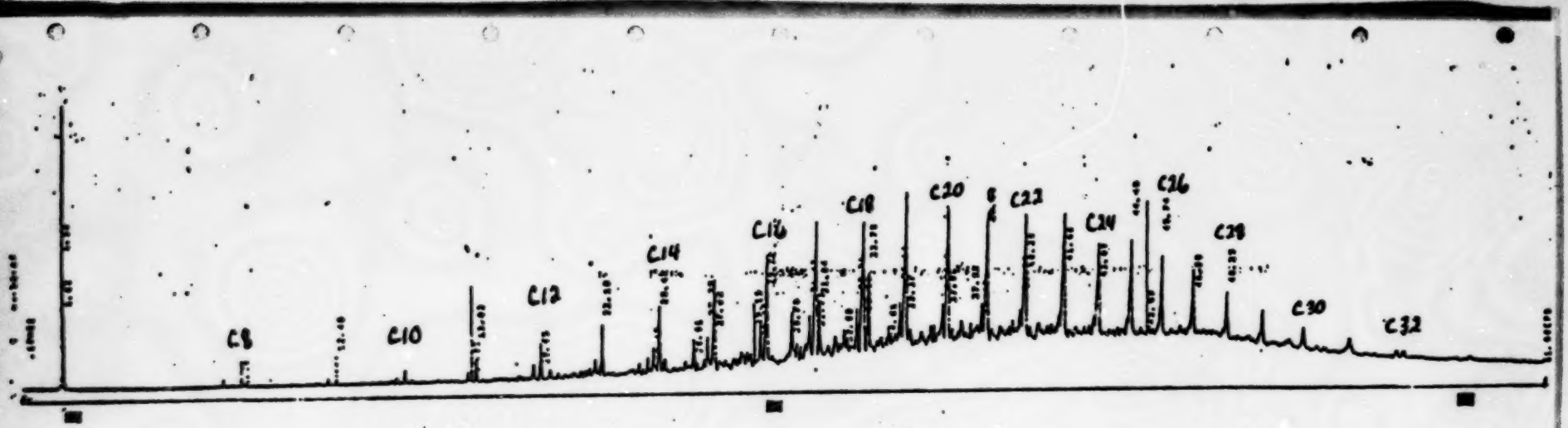

Figure A-7: Chromotogram for Test 3 (Cyclone)

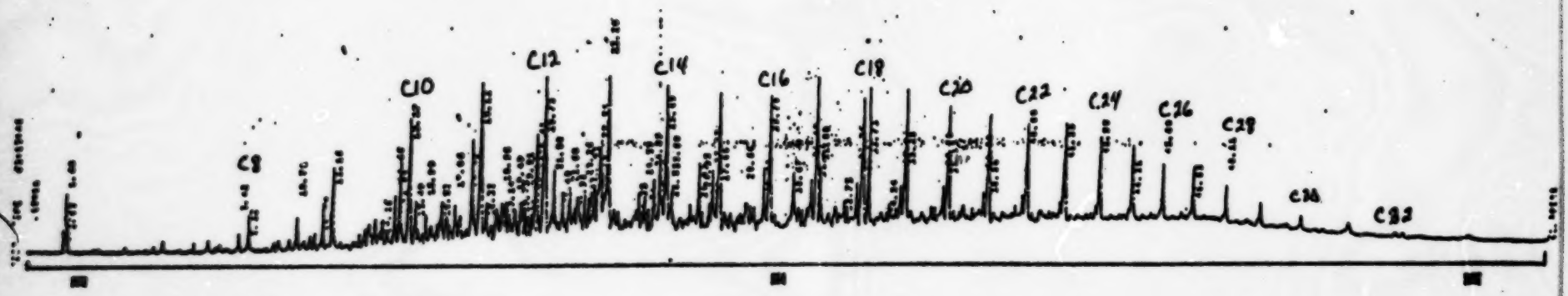

Figure A-8: Chromotogram for Test 3 (Condensor)

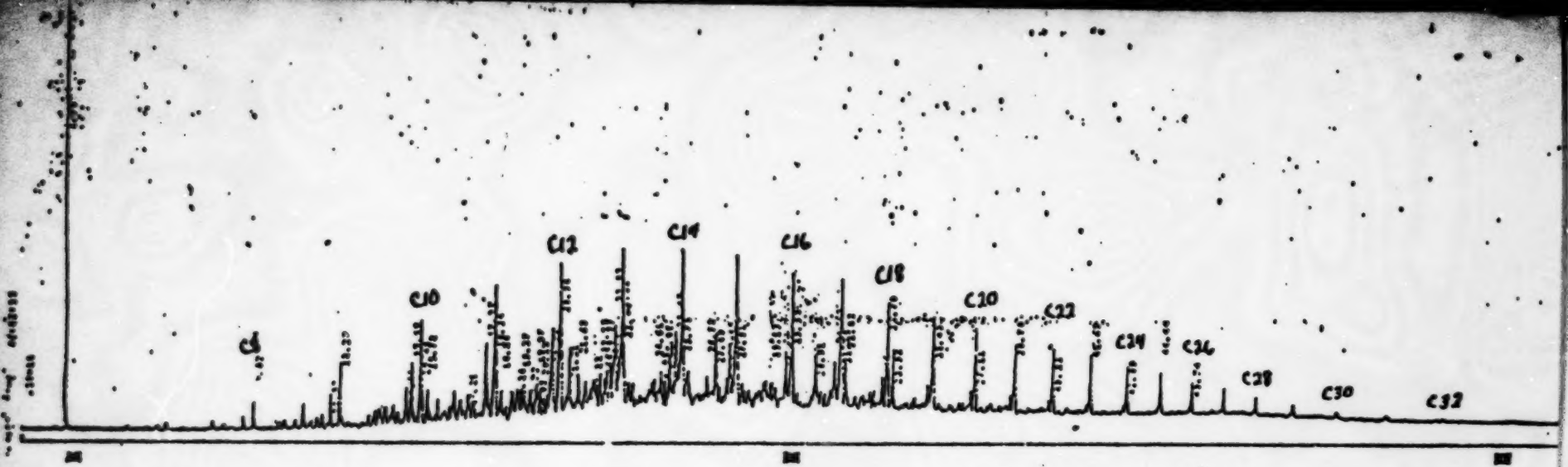

Figure A-9: Chromotogram for Test 3 (ESP)

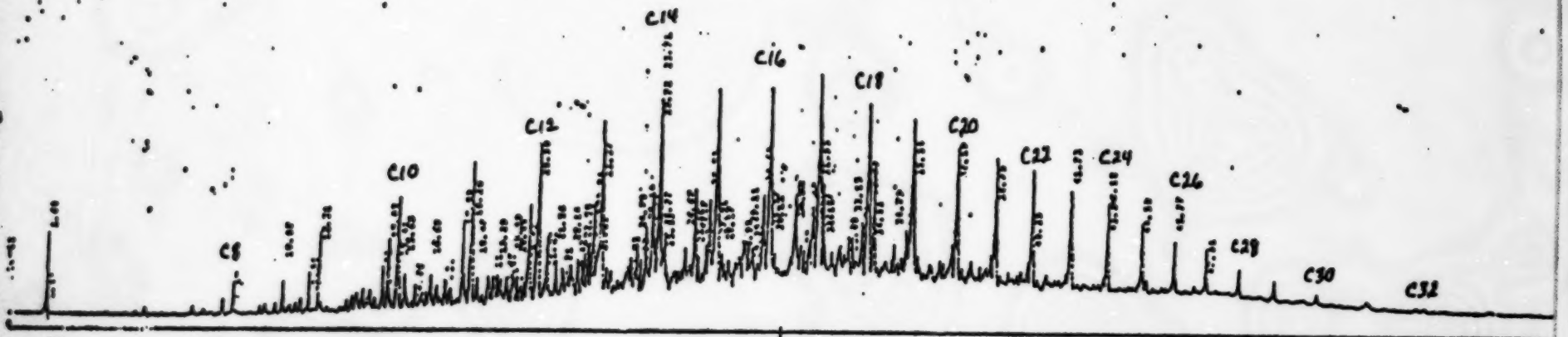

Figure A-10: Chromotogram for Test 3 (Column)

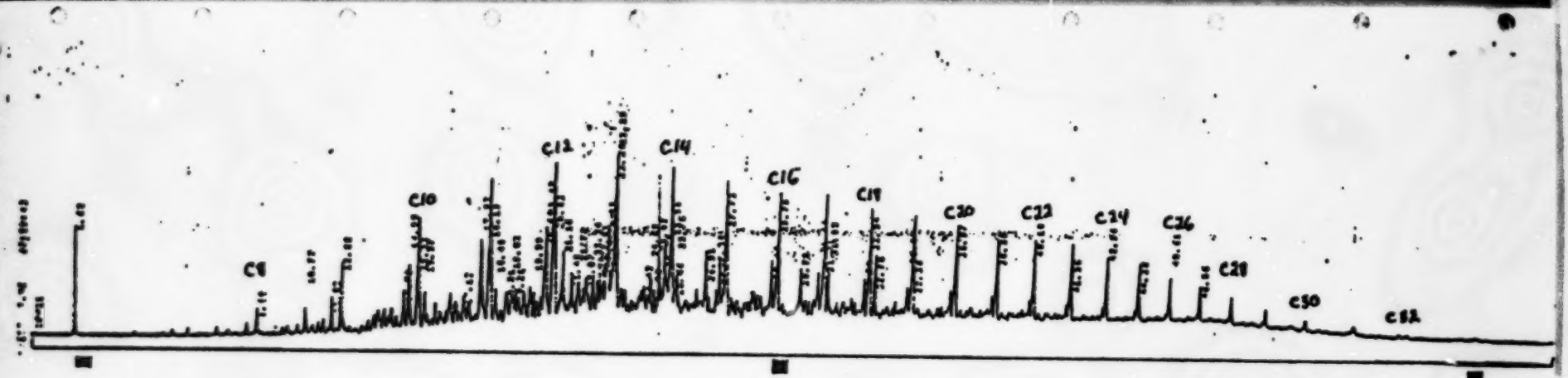

Figure A-11: Chromotogram for Test 4 (Cyclone)

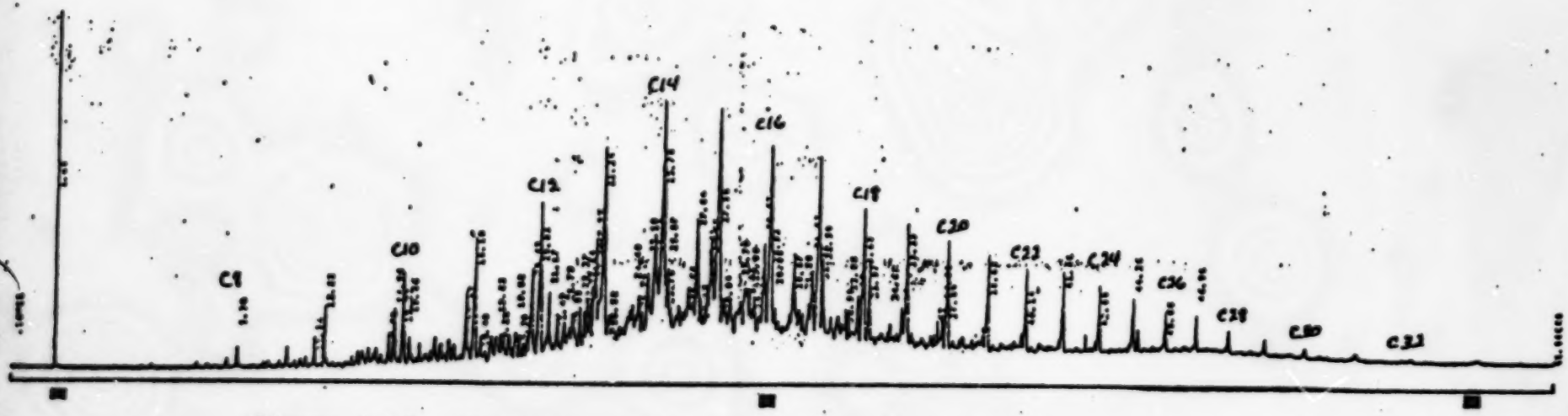

Figure A-12: Chromotogram for Test 4 (Condenser)

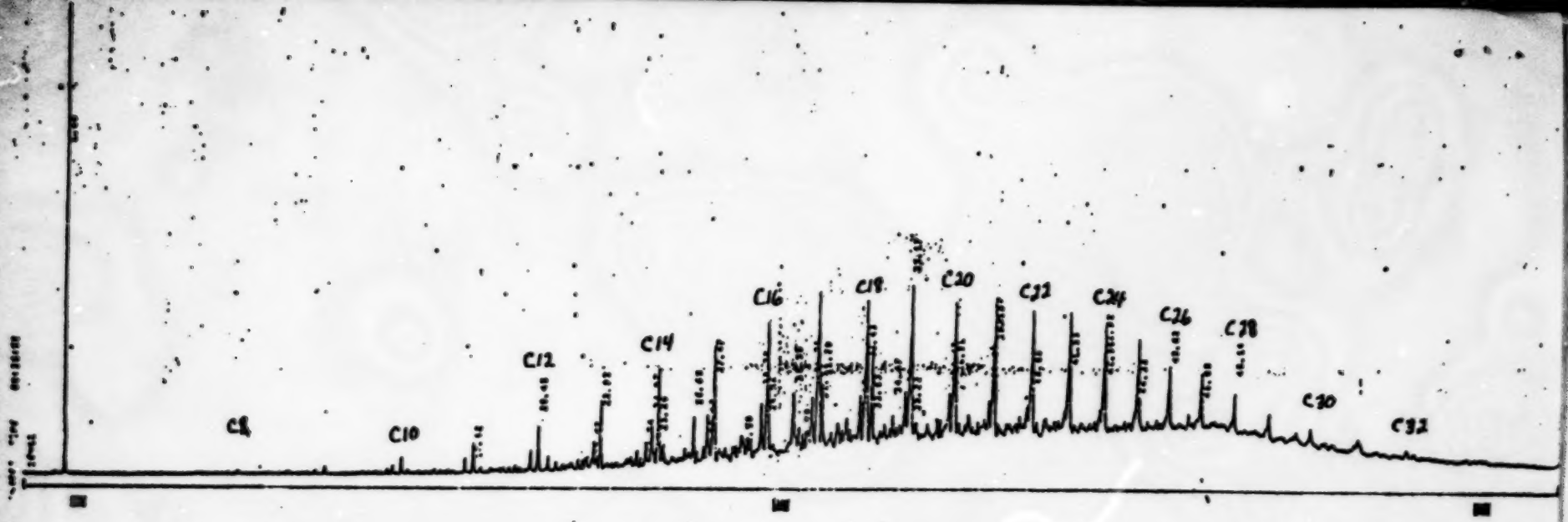

Figure A-13: Chromotogram for Test 4 (ESP)

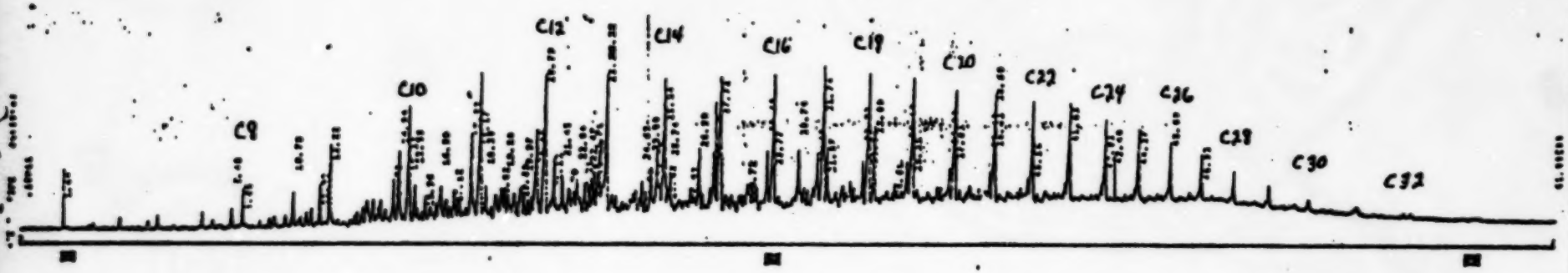

Figure A-14: Chromotogram for Test 4 (Column)

and the column in that order. Also, since the table is derived from Figures A-1 to A-14, the figures show the same trend.

Published data (7) for oil products from Green River oil shale using ASTM distilation shows that 60% of the oil boils at temperatures greater than 434°C. Although it is difficult to compare ASTM distillation with the results using chromatography with certainty, according to Table A-1, in excess of 98% of all the oil products have a boiling point below 413°C. This is another indication that New Brunswick shale oil is much lighter than Green River oils.

Gas Analysis

Product gas yields are given in Table 4 and Figure A-15 shows chromatograms of the product gases. The figure shows qualitative gas compositions at various time intervals for runs 2, 3 and 4. In this figure methane represents the major hydrocarbon constituent of the gases.

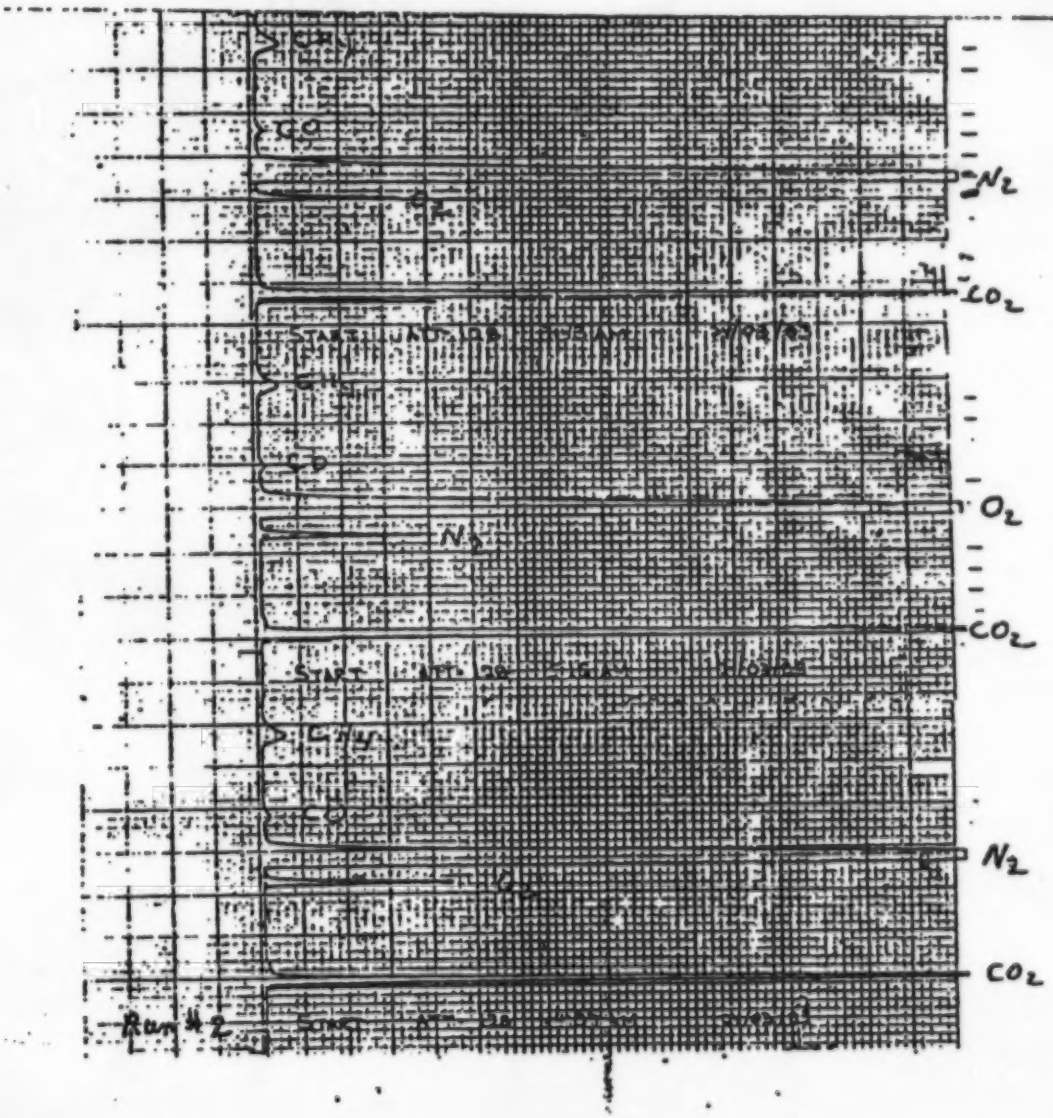

FIGURE A-15: CHROMOTOGRAMS OF GAS COMPOSITIONS AT DIFFERENT TIME INTERVALS (Run #2)

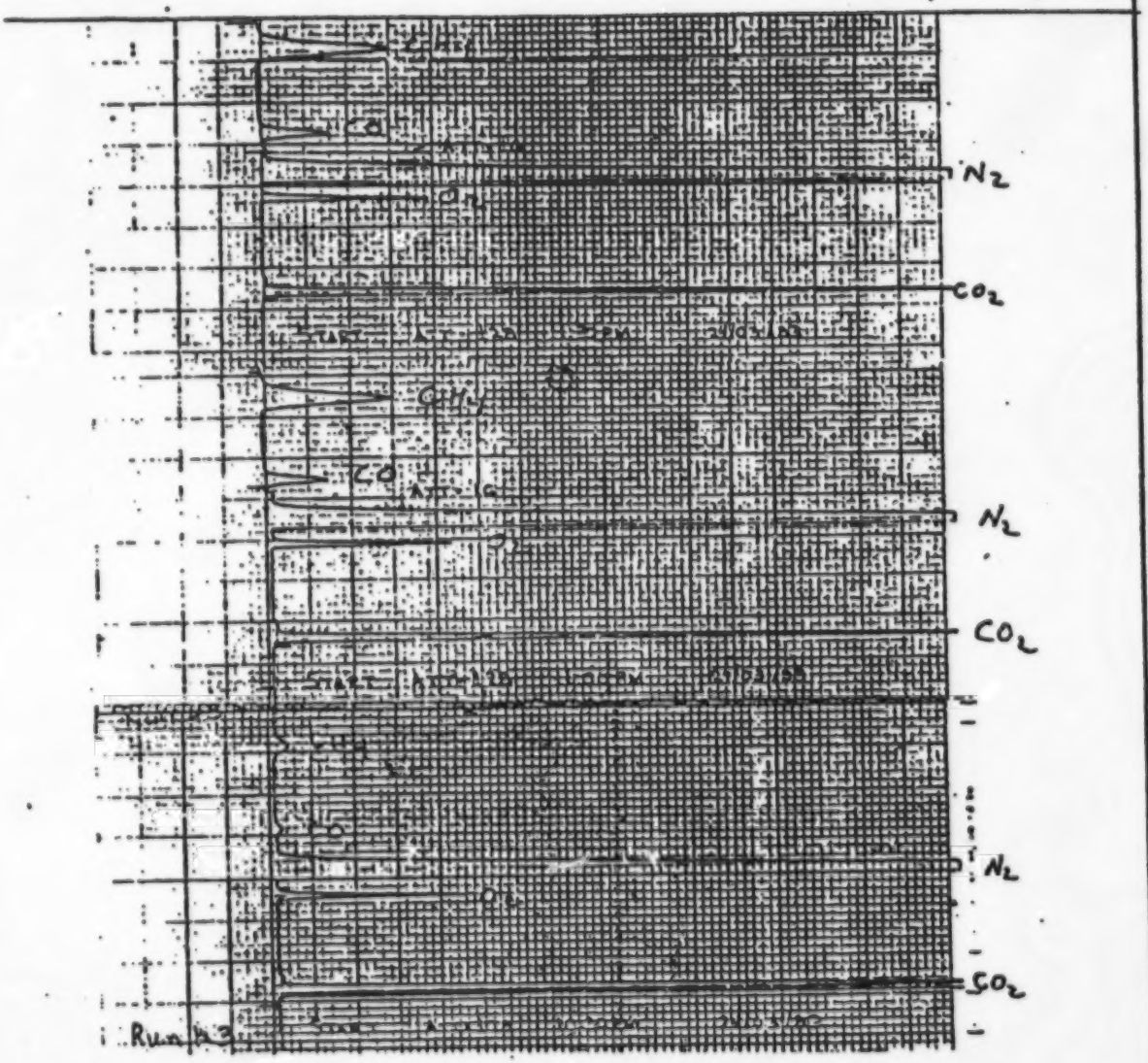

FIGURE A-15: CHROMOTOGRAMS OF GAS COMPOSITIONS AT DIFFERENT TIME INTERVALS (Run #3)
(Cont'd)

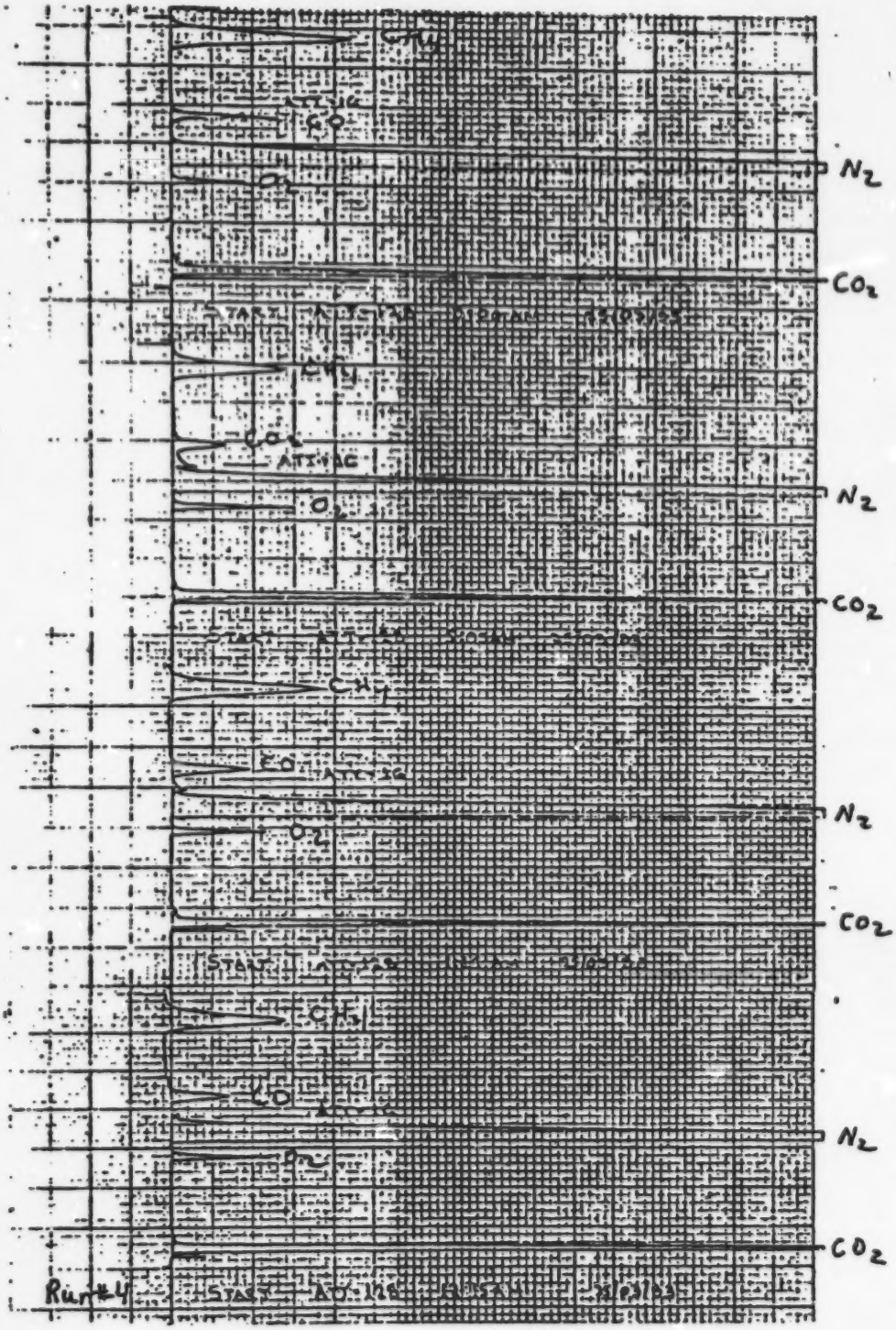

FIGURE A-15: CHROMOTOGRAMS OF GAS COMPOSITIONS AT DIFFERENT TIME INTERVALS (Run #4)
(Cont'd)